Reduction of LWR by Advanced Polymer bound PAG based EUV resist

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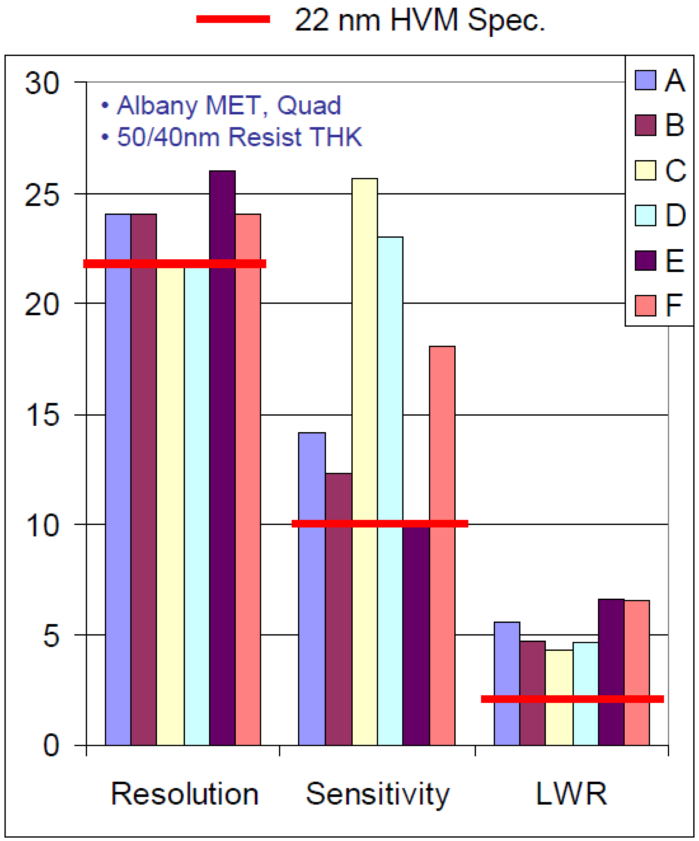
Outline

1. Background
2. Acid diffusion study
3. LWR improvement by advanced PAG polymer
4. Image contrast enhancement
5. Smoothing process
6. Summary

Background

Key Gap for 22 nm Patterning

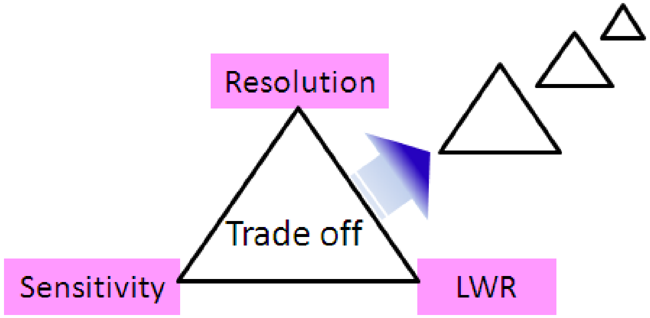


Goal 22 nm HP 10mJ/cm² 1.4 nm

- Key Gaps for 22 nm HP Patterning

1. LWR
2. Collapse
3. Sensitivity
4. Resolution

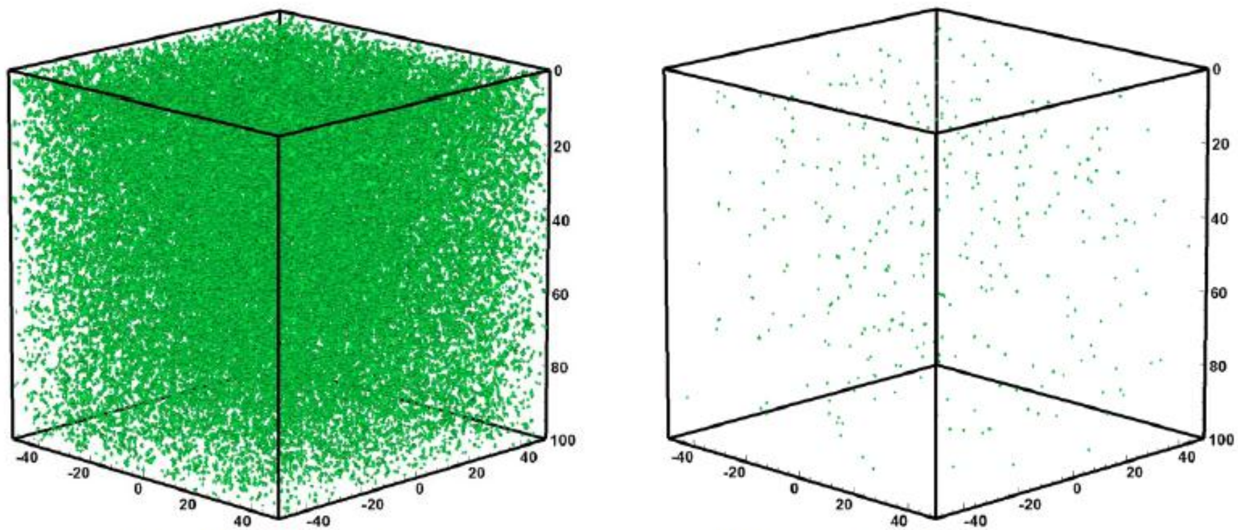
5. Defect (bridge/scum)
6. Pattern transfer with thin resist



Kyoungyong Cho, EUV Symposium, Kobe 2010

Photon comparison ArF vs. EUV

Fig. 1 - A comparison of photon counting at ArF and EUV in a volume when absorbance coefficient and dose are constant across wavelength. About 14X fewer photons are absorbed at EUV vs. ArF.



$ArF, 10\,mJ/cm^2, \alpha = 4/um$

$n_{absorbed} = 366528, E_{absorbed} = 2354\,keV$

$EUV, 10\,mJ/cm^2, \alpha = 4/um$

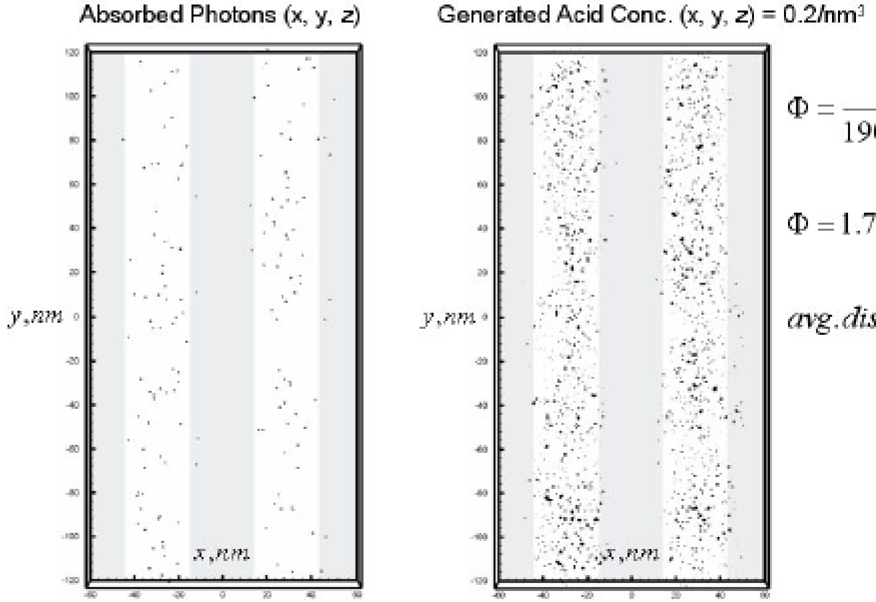
$n_{absorbed} = 25328, E_{absorbed} = 2326\,keV$

X1/14 fewer photons at EUV

John J. Biafore, SPIE 2009, Vol.7273, 727343

Shot noise impact on LWR

Fig. 7 - Simulation of photon absorption and the acid shot noise image, at EUV, 30 nm lines, 2-beam imaging, Esize. Simulated quantum efficiency is 1.74. Acid 'clumps' are visible about photon absorption sites.



Few absorbed photons   Acid shot noise

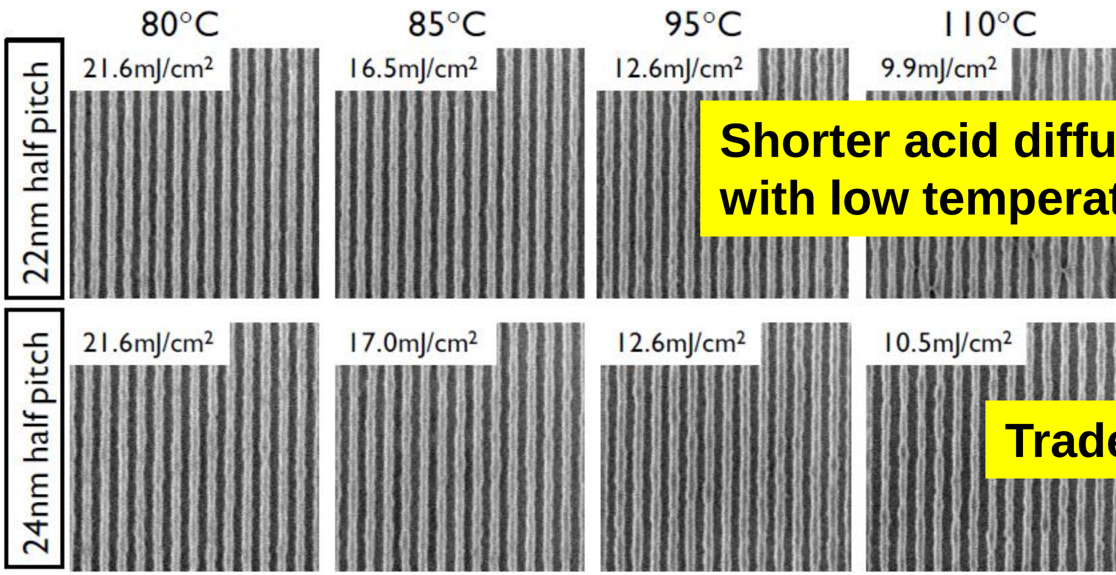
$$\Phi = \frac{33116\, acids}{19059\, abs.\, photons}$$

$$\Phi = 1.74$$

$$avg.dist.between\, acids = 4\, nm$$

John J. Biafore, SPIE 2009, Vol.7273, 727343

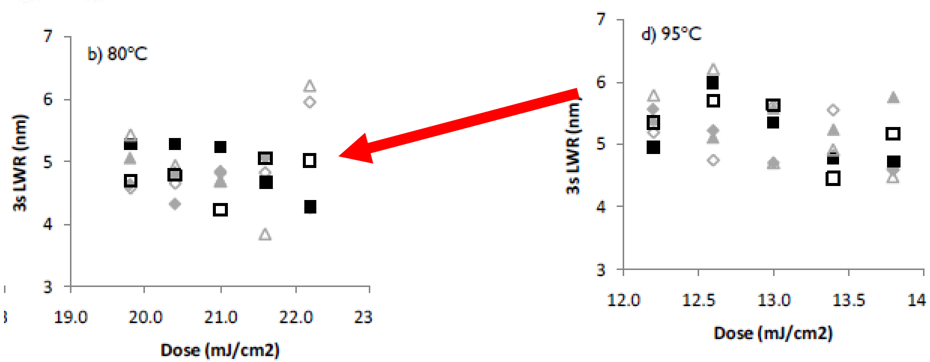
Acid diffusion impact on LWR



Shorter acid diffusion and smaller LWR with low temperature PEB

Trade off sensitivity

Figure 2. Patterning performance near best dose/best focus across PEB temperature at 22nm (top) and 24nm (bottom) half pitch resolution using C-Dipole illumination on the 0.3NA MET.



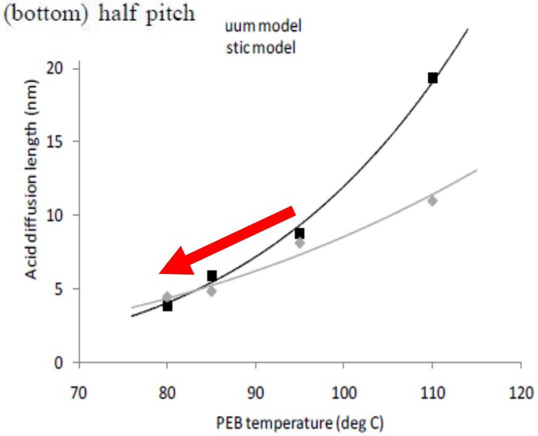
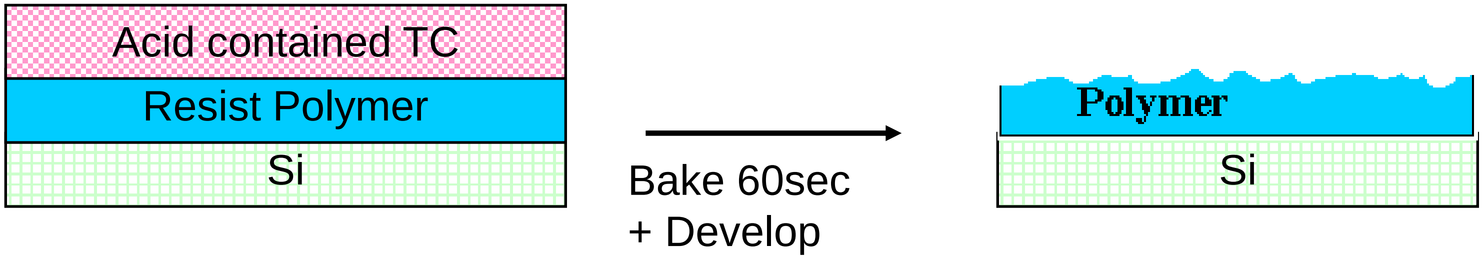


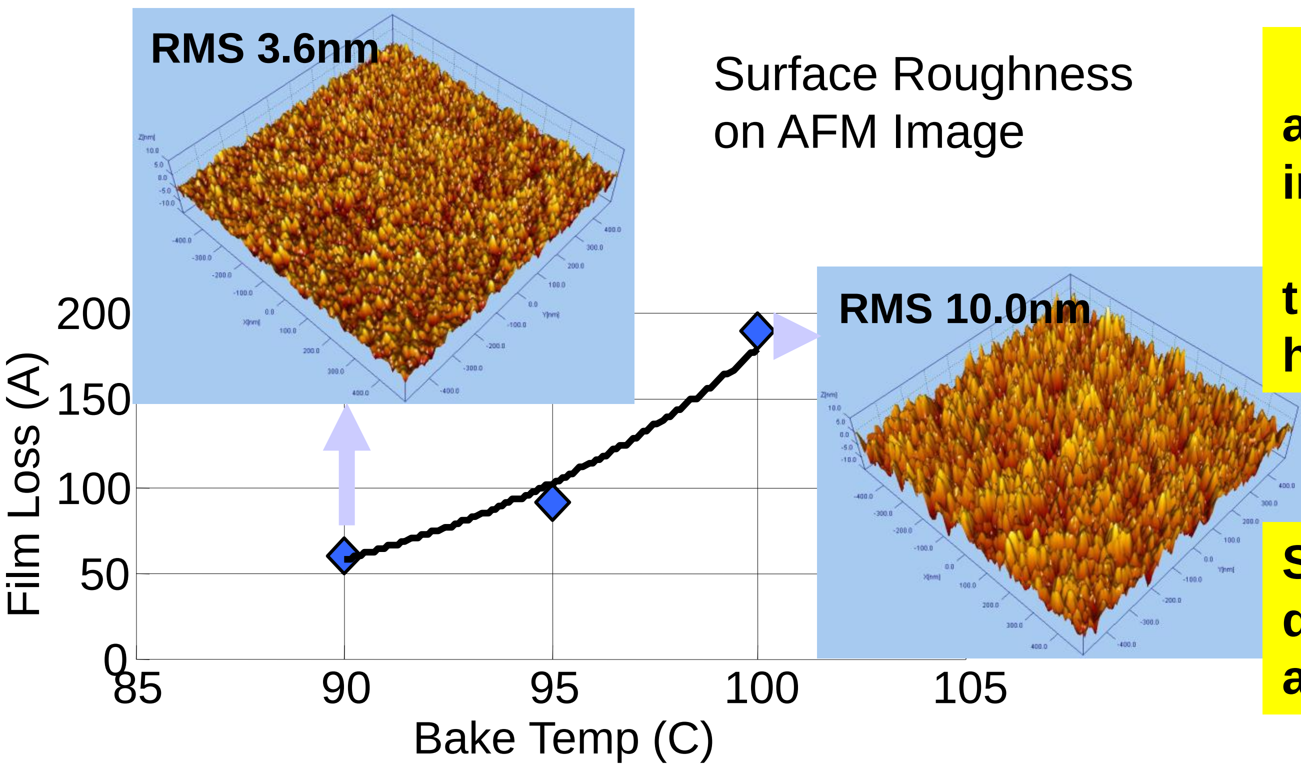
Figure 10. Extracted acid diffusion length from the PROLITH continuum (black) and stochastic (grey) model for the studied PEB settings. Especially at the low PEB temperature range the results are in excellent quantitative agreement with a minimum diffusion length ~4nm.

Roel Gronheid, SPIE 2011, Vol.7969, 796904

ADI surface roughness dependence on acid diffusion length

Experimental



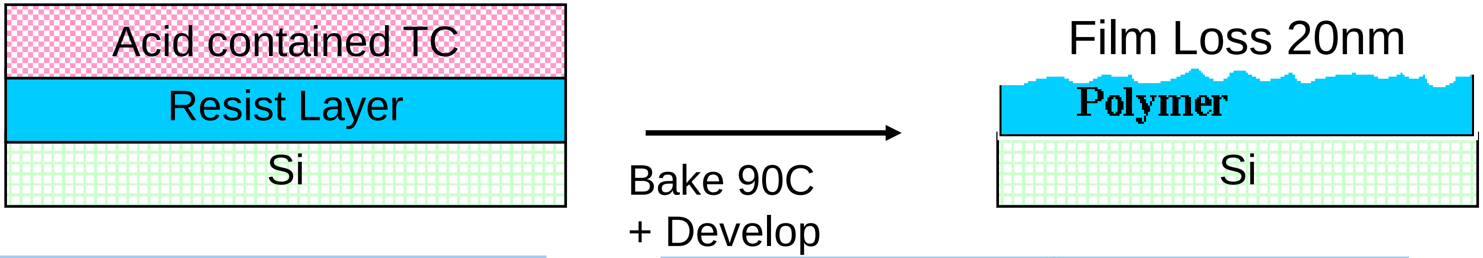


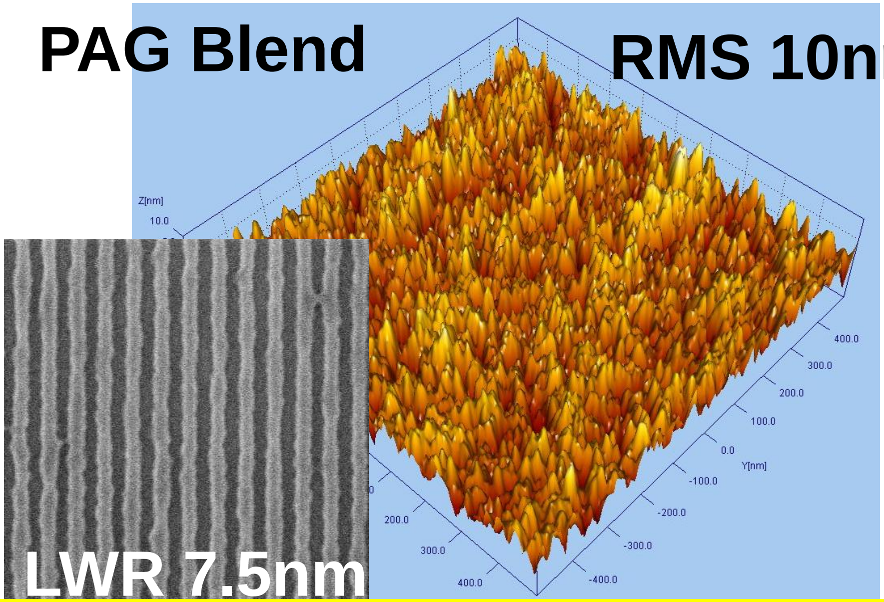
Roughness Increases as the acid diffusion increases.
This result indicates that the acid diffuses heterogeneously.

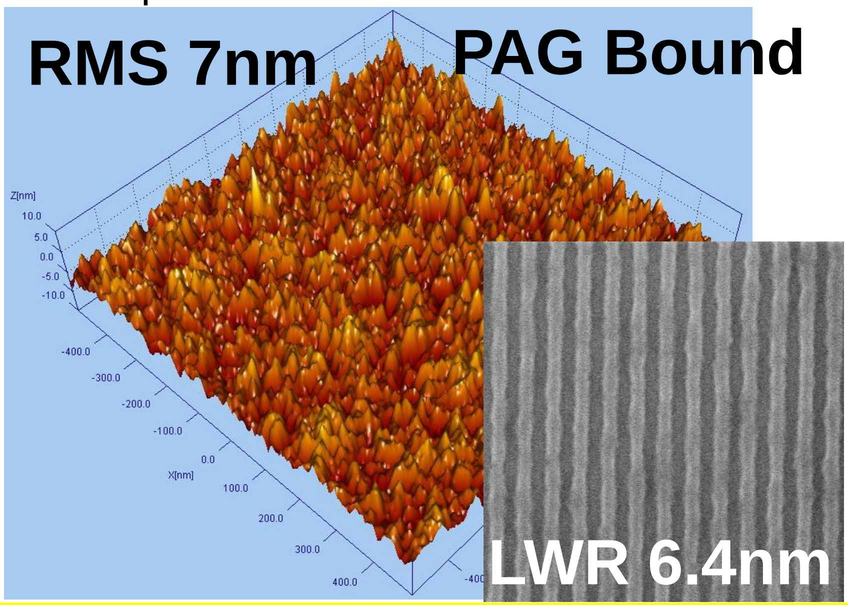
Shorten the acid diffusion should achieve better LWR.

Surface roughness comparison between PAG blend and bound

Experimental







Bound PAG shows better roughness than that of blend at the same film loss. This result indicates that acid diffusion in bound PAG polymer film is more homogeneous, and result in better LWR.

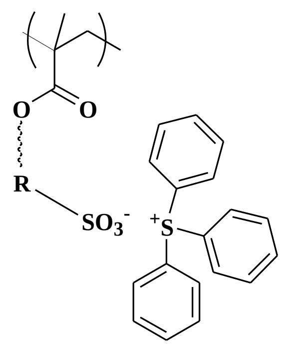
PAG Bound Polymer Characteristics
EUV interferometric exposure at PSI

	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}
MET-2D	**100**	13.4	2.24E+16	22.7	90	0.12	8.1	32	**0.73**
	90	13.4	2.24E+16	24.6	90	0.11	8.7	32	**0.83**
Blend A	**100**	13.4	2.24E+16	22.8	80	0.17	6.3	26	**0.62**
	90	13.4	2.24E+16	25.0	80	0.16	6.1	26	**0.66**
EUV-B	**100**	13.4	2.24E+16	41.1	80	0.21	4.9	17	**0.43**
	90	13.4	2.24E+16	45.2	80	0.23	4.4	17	**0.49**
EUV-C	**100**	13.4	2.24E+16	37.7	80	0.23	4.6	13	**0.28**
	90	13.4	2.24E+16	42.0	80	0.24	4.8	13	**0.36**

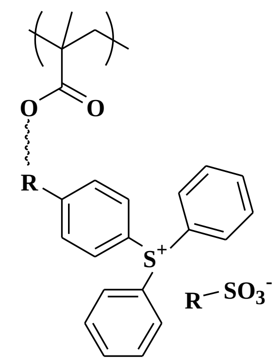
PAG Blend Methactylate

2007 EUV Symposium Sapporo
David Van Steenwinckel(NXP)
RoelGronheid, Patrick Willems, Frieda Van Roey(IMEC)

Anion Bound PAG Methactylate



Cation Bound PAG Methactylate



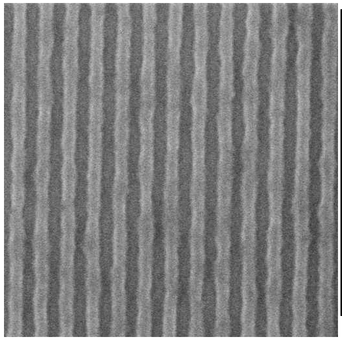
The shortest acid diffusion and lowest LWR can be attained with anion bound PAG.

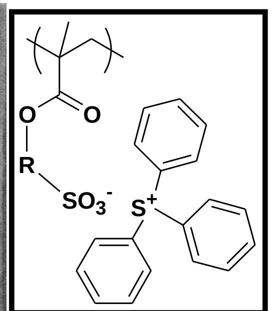
Courtesy of IMEC

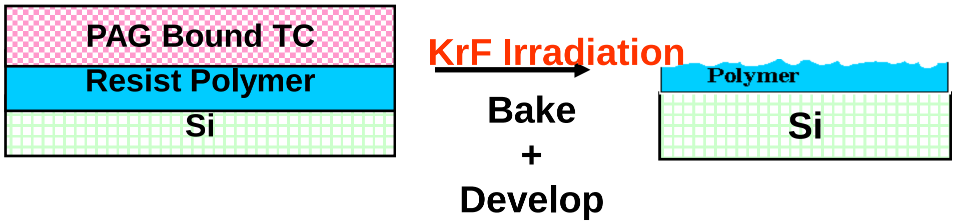
PAG Modification 1st step
Bulky anion

26nmLS

10.0mJ/cm²
LWR6.4nm



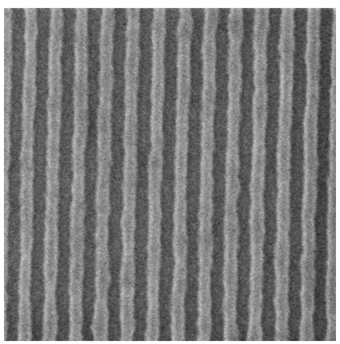


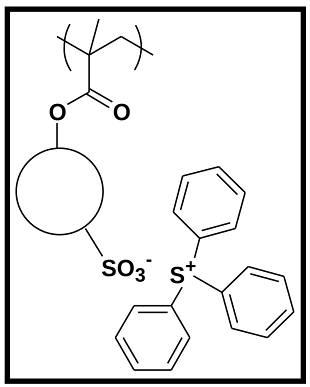


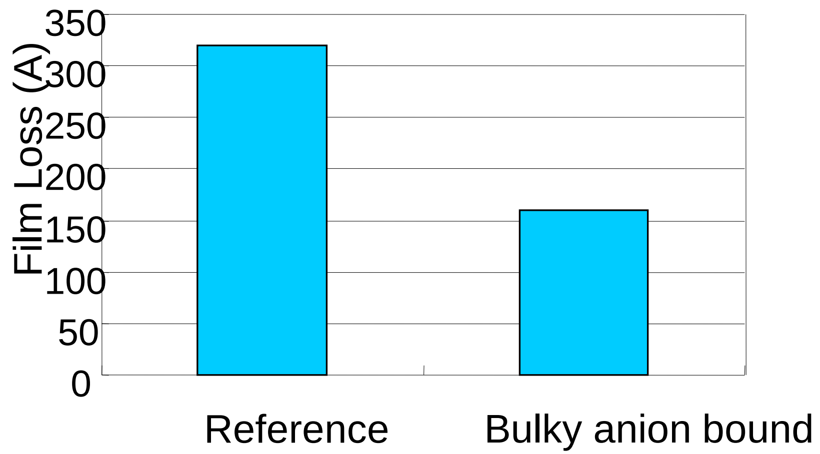
26nmLS

Bulky anion bound

14.7mJ/cm²
LWR5.6nm







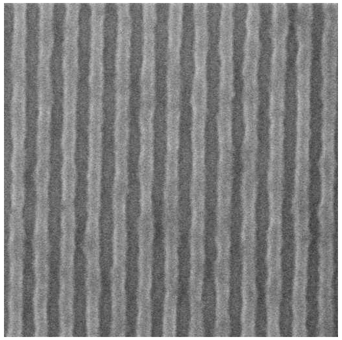
Bulky anion bound PAG acid diffusion length shows half of ref., which successfully reduces LWR.

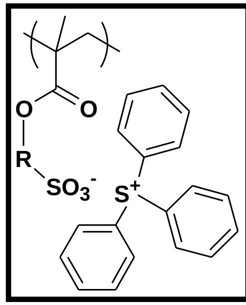
EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm

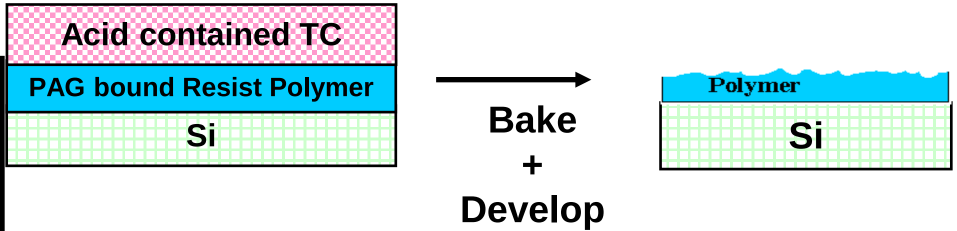
PAG Modification 2nd Step
Bulky cation

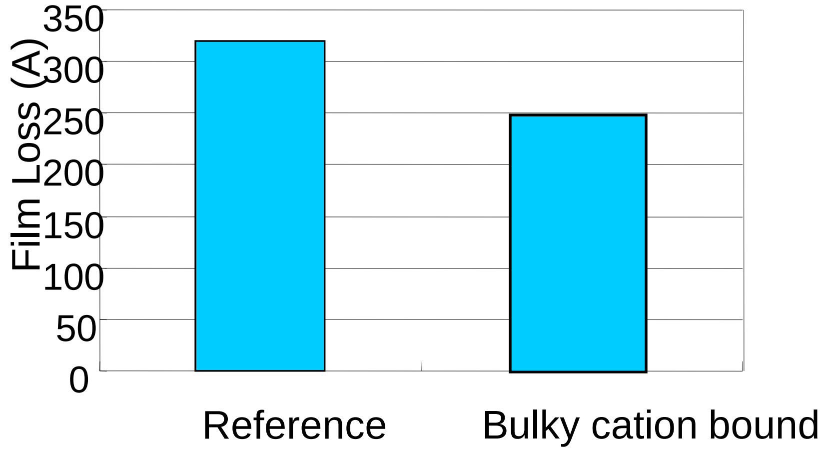
26nmLS

10.0mJ/cm²
LWR6.4nm





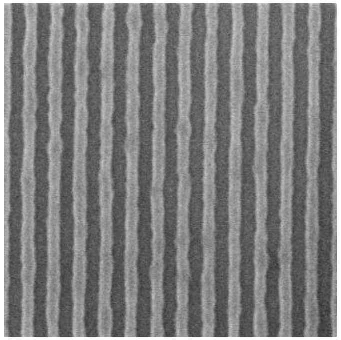


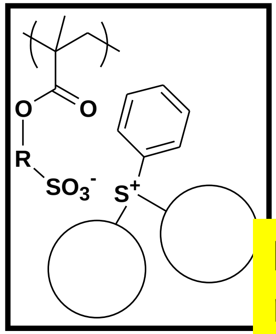


Bulky cation bound

26nmLS

11.24mJ/cm²
LWR4.7nm





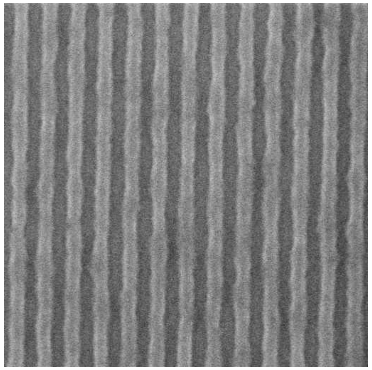
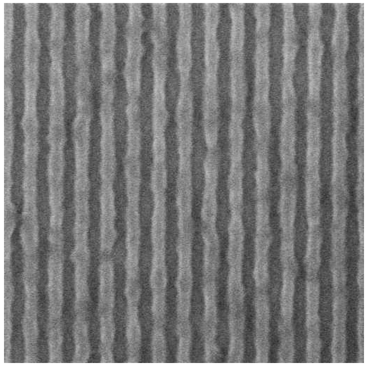
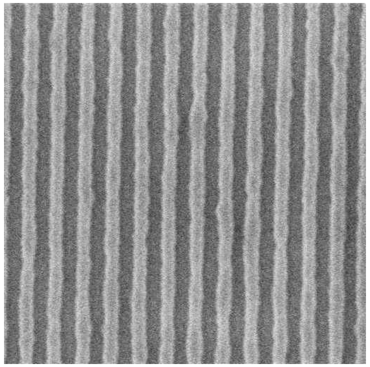
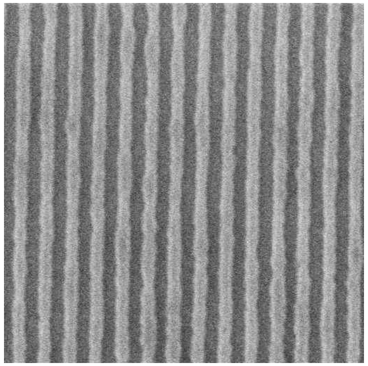
Bulky cation bound PAG acid diffusion length reduces LWR.

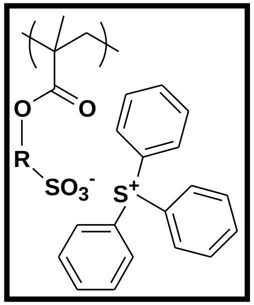
EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm

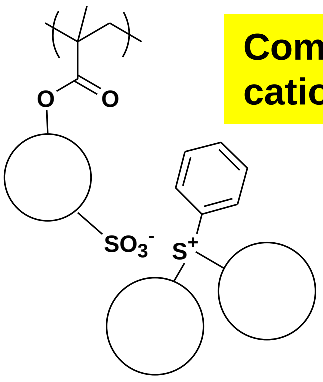
Bulky cation reduces OOB effect and outgas

PAG Modification 3rd Step
Bulky anion / cation

EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm

	26nmLS	24nmLS
PAGx1.0 **Qx1.0**	 Dose 10.00mJ/cm2 **LWR 6.4nm**	 Dose 11.00mJ/cm2 **LWR 7.4nm**
PAGx2.0 **Qx1.7**	 Dose 13.77mJ/cm2 **LWR 4.5nm**	 Dose 14.50mJ/cm2 **LWR 5.4nm**



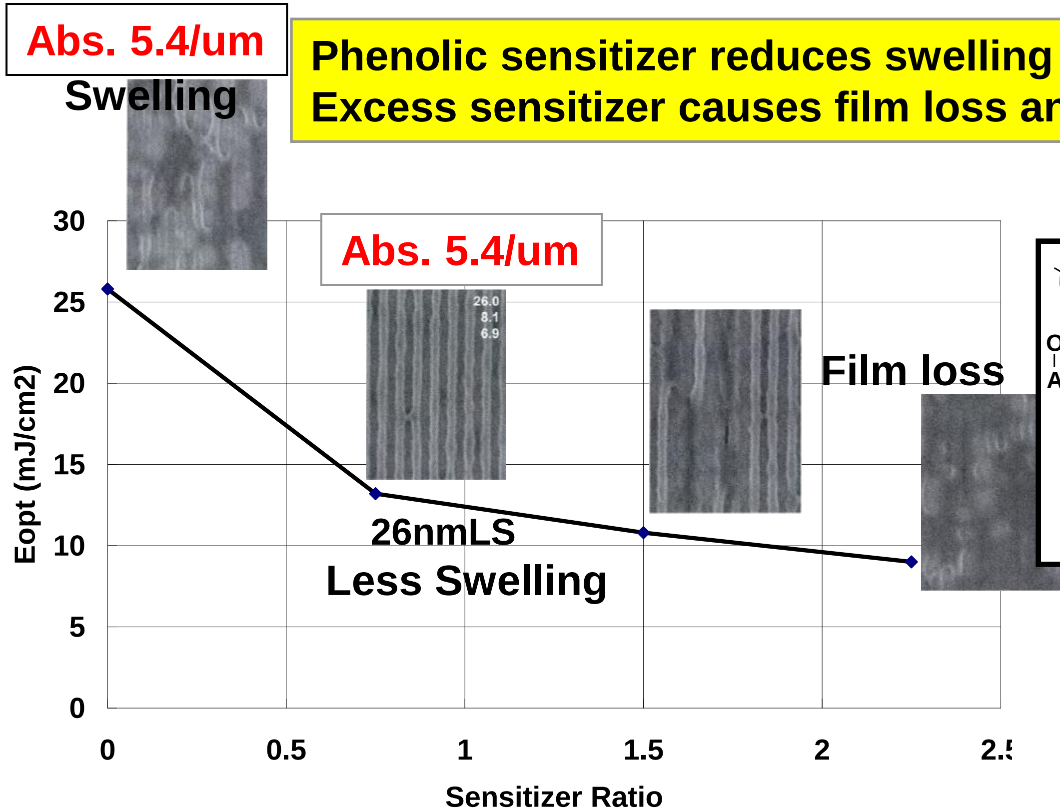


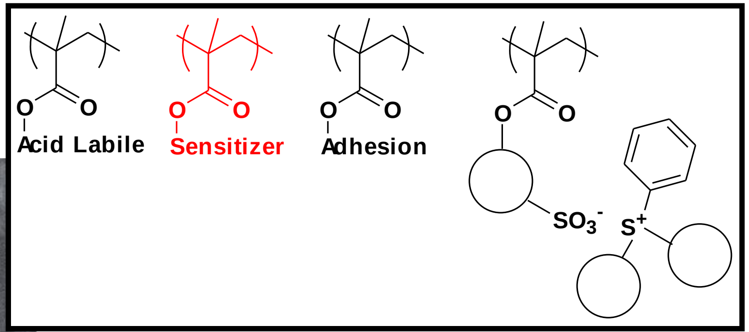
Combination of bulky cation and bulky anion

Higher concentration of small diffusion PAG improves LWR.

Higher sensitivity & better LWR design

Phenolic sensitizer reduces swelling to improve collapse.
Excess sensitizer causes film loss and collapse.





Concept for advanced sensitizer design
1) Higher ionization efficiency
2) Improve LWR, prevent collapse

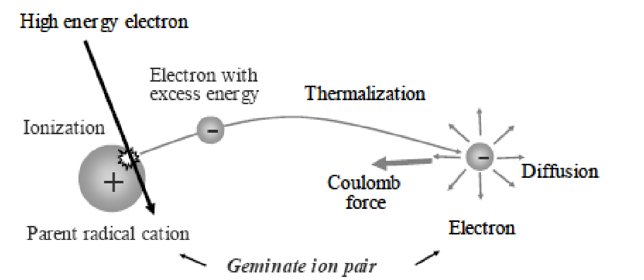
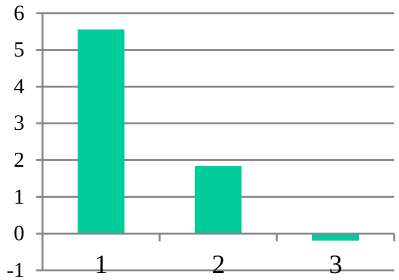


Figure 1. Schematic drawing of early processes of radiation chemistry.

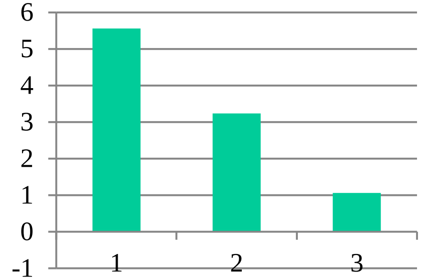
Prof. Kozawa and Tagawa SPIE Vol.5753 (2005)

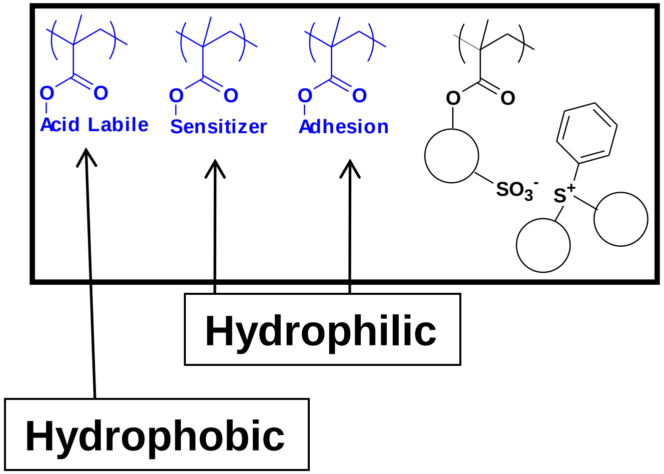
Hydrophobisity control for LWR improvement

Big polarity difference

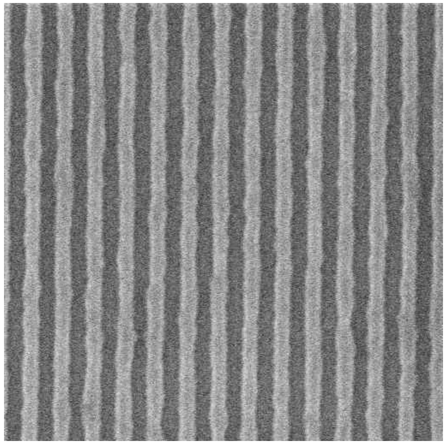


Small polarity difference

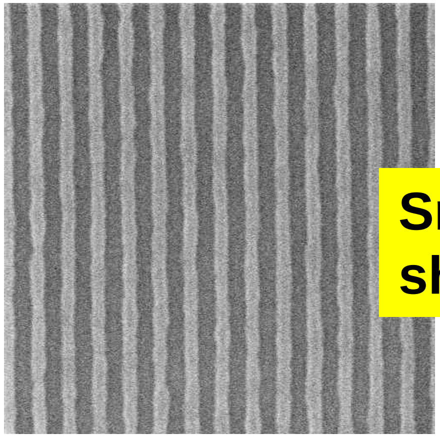




24nmLS



Dose 17.90mJ/cm2
LWR 4.5nm



Dose 18.90mJ/cm2
LWR 4.0nm

Small polarity variation shows smaller LWR

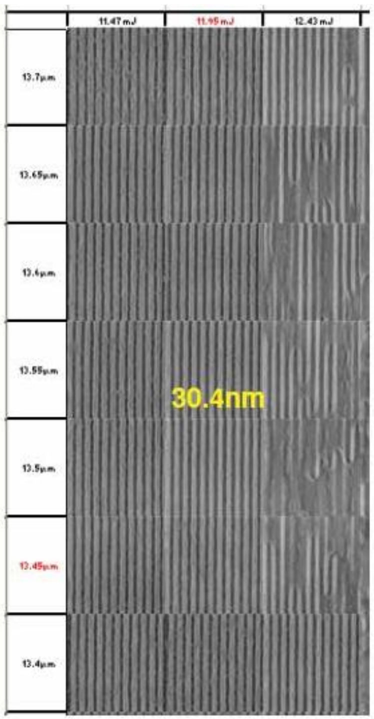
EUV MET
NA0.3 0.36/0.93
Quadrupole
Resist FT 40nm

ED window expansion by smaller LWR

TMAH development
DIW Rinse

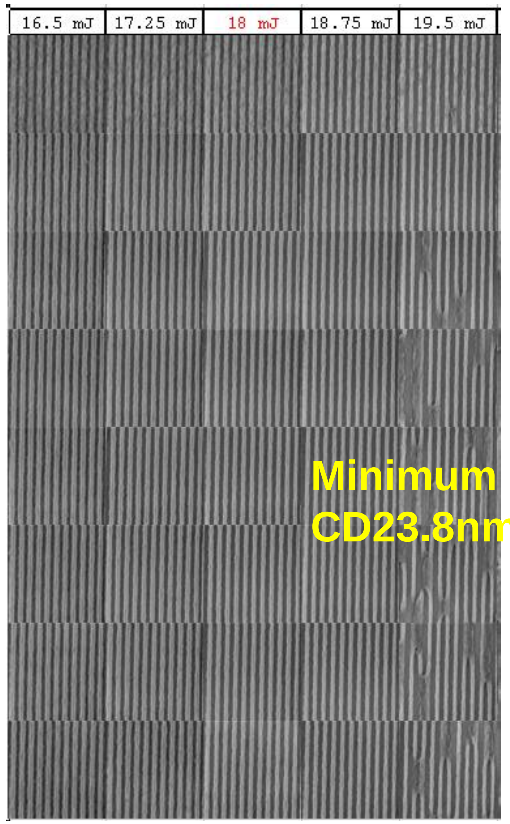
EUV MET
NA0.3 0.36/0.68
Quadrupole

Resist A
75nm FT
30nmLS



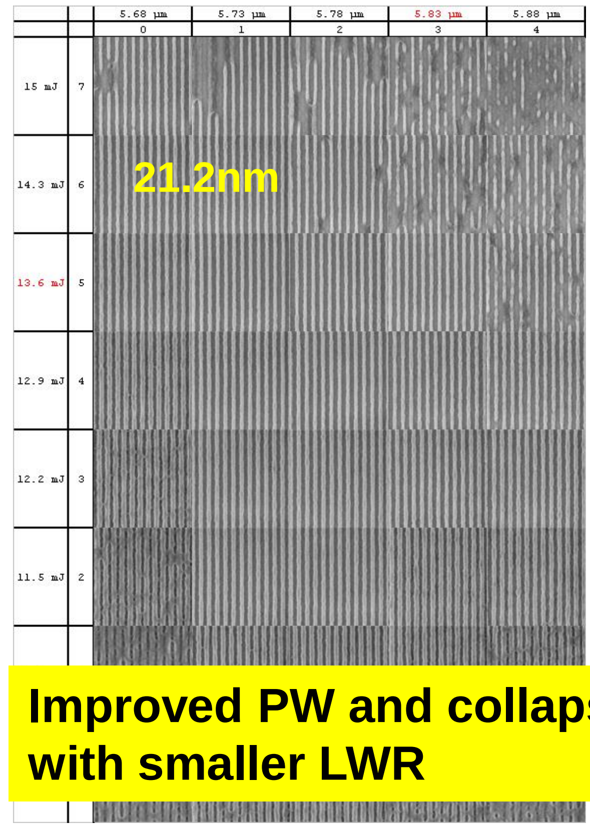
LWR5.2

Resist B
75nm FT
30nmLS



LWR4.8

Resist C
60nm FT
28nmLS

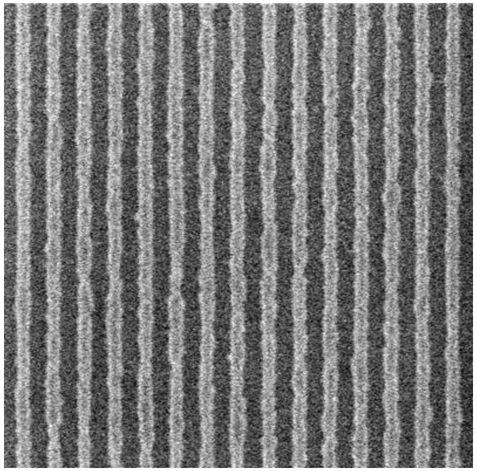


LWR3.8

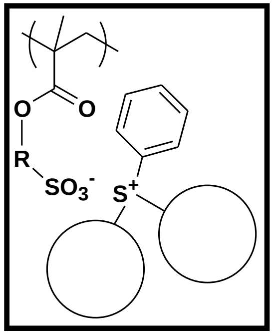
Improved PW and collapse with smaller LWR

Image contrast enhancement

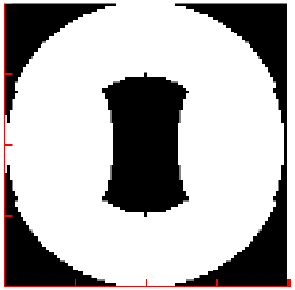
22nmLS



LWR 5.2nm



NA blocker
Design 22nmLS



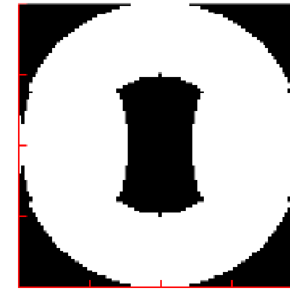
EUV ADT
NA0.25
NA Blocker

Greg McIntyre, et al,
"Enhancing Resolution of the Albany ADT with Pupil Filtering“
EUVL Symposium, 2012

Resolution enhancement & LWR improvement by high contrast optical image

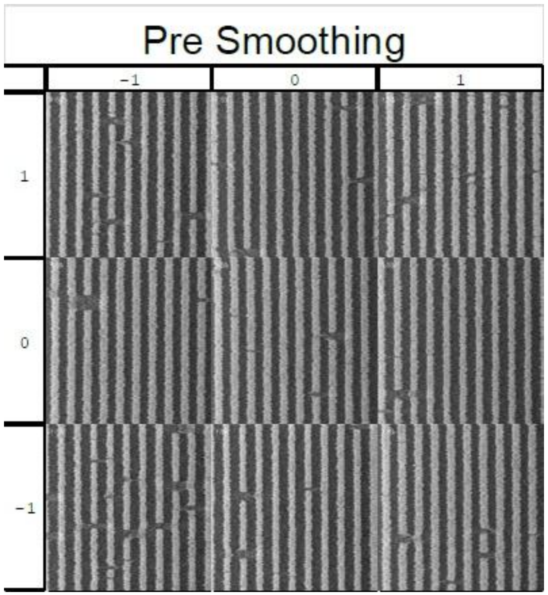
Post development smoothing process

NA blocker
Design 22nmLS



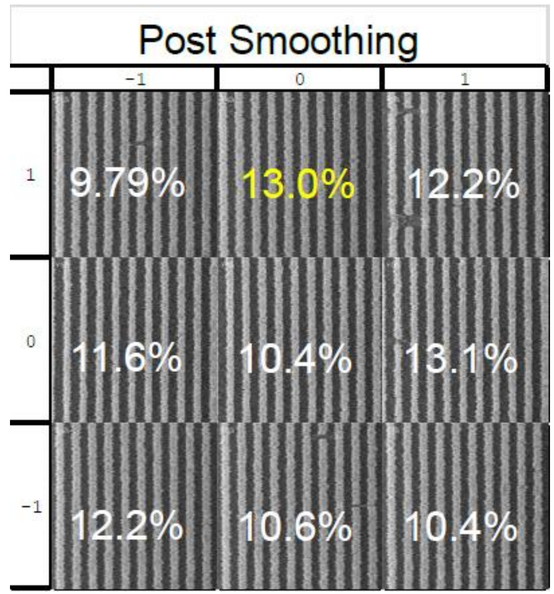
EUV ADT
NA0.25
NA Blocker

22nmLS



LWR7.0

22nmLS



LWR6.2

11.5% Improved

Karen Petrillo et al, "Level Specific Material Evaluations for NXE3300 Applications," EUVL Symposium, 2012

Summary

1. Bulky anion / bulky cation of small diffusion PAG with high loading to improve LWR
   PAG is dominant for progress.
2. Sensitizer and polarity control to improve LWR
3. PW expansion by LWR improvement
4. High contrast images to improve LWR
5. Post development smoothing process to reduction LWR

Acknowledgment

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TEL

Takashi Saito